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Spectral Characteristics of Cross-Field and Two Stream Instability as Revealed by Rocket Borne Studies*

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Abstract. Rocket borne probe studies of plasma instabilities carried out over Thumba (magnetic dip = 0.8° s) in E region heights have shown that:

i) Crossfield instability can produce scale sizes ranging from hundred meter to a few meter while two stream instability produces only meter scale size irregularities.

ii) The spectral index of cross-field produced irregularities is −3 while the irregularities produced by two stream instability have flat spectrum.

Both of these features are discussed in detail in this paper. In addition dependence of scale size on density gradient and drift velocity is also discussed. Results of rocket induced irregularities are also presented.

Key words: Equatorial E region – Equatorial electrojet – Plasma instability – Spectral index – Crossfield instability – Two stream instability.

Introduction

The properties of equatorial E region irregularities have been extensively studied by rocket borne probes as well as by ground based backscatter radar (e.g. Prakash et al., 1970, 1971 a, b; Balsley and Farley, 1971). It was established that crossfield and two stream instabilities are the main mechanisms responsible for producing irregularities in the equatorial E region. In this paper we shall discuss some spectral properties of E region irregularities with scale sizes between 1 and 15 m as revealed by rocket borne Langmuir probes at Thumba (India). In addition we shall also discuss the spectral properties of such irregularities as are induced by the rocket itself. These latter were observed between 160 to 200 km height, the apogee height range of Nike-Apache rockets.

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Experimental Technique and Procedure for Data Analysis

A Langmuir probe system was designed for studying electron density, electron density fluctuations and power spectrum of density irregularities. The Langmuir probe system consists of an ogive shape electrode made of stainless steel. The area of the sensor is about 20 cm^2 and is fitted at the front portion of the rocket nose cone forming the tip of the rocket nose cone. The sensor is connected by a cable to an electrometer amplifier. A sweep voltage is applied to the sensor with respect to rocket body. The sweep voltage varies from -2 V to $+4$ V in 1 s, and for 1 s the sensor is kept at $+4.0$ v. The total time of one sweep is 2 s. The electrometer amplifier converts input current into voltage. This voltage is telemetered on I.R.I.G. channel no. 14 by FM/FM telemetry system. In order to study probe current fluctuations i.e. density irregularities the electrometer amplifier output is fed to an audio amplifier which has a frequency band width of 70 Hz to 1000 Hz. The audio amplifier gain is automatically controlled depending on the electrometer amplifier output voltage. The probe current fluctuations are telemetered on I.R.I.G. channel no. 18, which has a frequency response of 1.0 KHz.

The probe current was converted into electron density by using a calibration factor of 1 microamp equal to 10^4 elec/c.c. (Prakash et al., 1970). The percentage density fluctuations amplitude is given by $\Delta N/N \times 100$, where ΔN is the absolute value of density fluctuations and N is ambient the density. In terms of electrometer amplifier output $\frac{\Delta N}{N} = \frac{\Delta V}{V}$, where ΔV is the a.c. component in the frequency band 70 Hz to 1000 Hz, and V is the D.C. voltage at the output of the electrometer amplifier.

In order to calculate the scale sizes of density fluctuations along the direction of rocket motion the relation $V_{R/f}$ was used, where V_R is the rocket velocity and f the filter frequency. The frequency range 70 Hz to 1000 Hz corresponds to scale sizes of 1 to 15 m. The composite amplitude of density fluctuations in the frequency range 70 to 1000 Hz were subject to spectrum analysis using a spectrum analyzer consisting of six filters. The square of amplitude in each frequency band versus central frequency was plotted on a log-log graph and fitted on a power equation. The power equation used in this analysis is given by $E(K) \propto K^n$ where $E(K)$ is energy in wave number K and n is spectral index. The spectral index is an important parameter and gives information about a particular type of mechanism responsible for producing density fluctuations. For example the spectral index of the cross field instability mechanism is -3.00 while the spectral index of two stream generated irregularities lies between 0 to $+1.00$. It should be explained here that the spectral index zero does not mean that irregularities are produced due to noise but it means that the mechanism is such that it produces irregularities of equal amplitude in scale sizes 1 to 15 m.

Experimental Results

Three Nike-Apache rockets were launched from Thumba with a Langmuir probe payload. The electron density profiles obtained from these flights have been

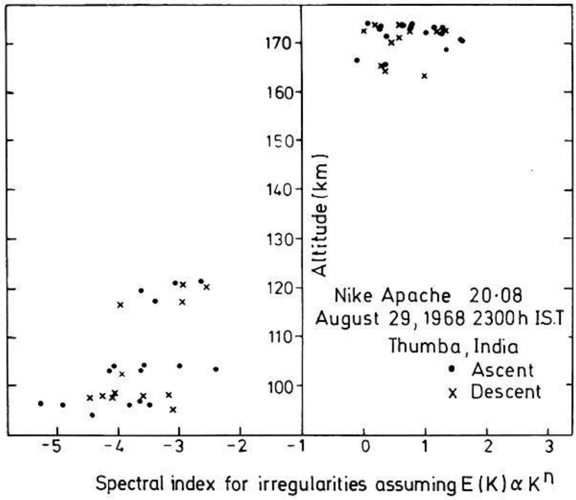

Fig. 1. Spectral index of night time irregularities

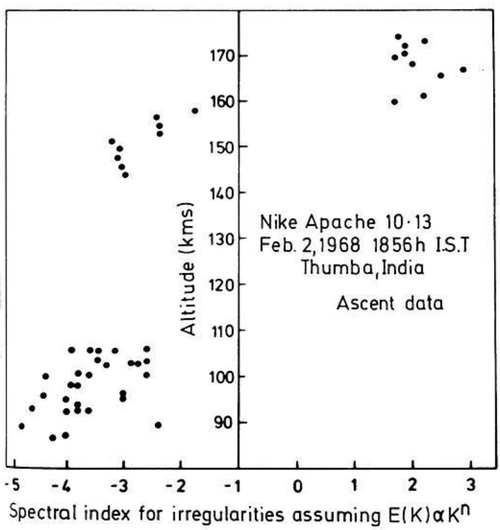

Fig. 2. Spectral index of evening time irregularities

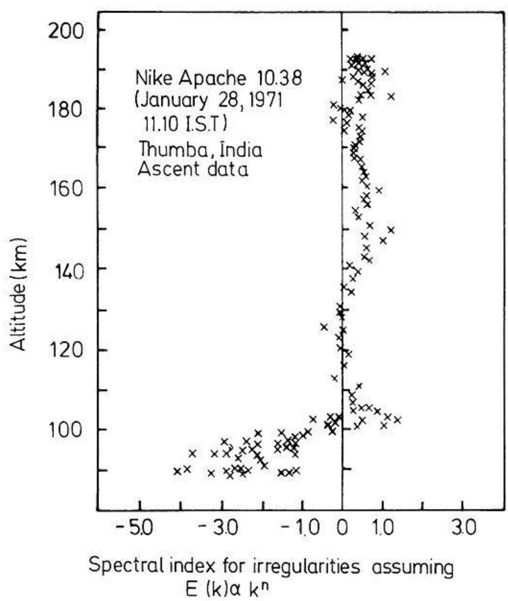

Fig. 3. Spectral index of noon time irregularities

published in our earlier publications. The composite amplitude of electron density irregularities is about 1 to 2% (Prakash et al., 1970, 1971a, b). In this paper we shall present results of spectral indices only. As already discussed the measurements were carried out along the direction of rocket motion. The fluctuations were studies when the sensor was kept at +4 V with respect to the rocket body. Figure 1 shows the spectral index values of a midnight flight, and Figure 2 shows the results of an evening flight. The spectral index values are negative in the height region

85 to 155 km but positive at the rocket apogee heights. Figure 3 shows the results of a noon time flight. On this flight the spectral index is negative between 90 to 100 km. However, near rocket apogee the spectral index is positive on this flight also.

Discussion

We shall now discuss the occurrence of certain ranges of spectral index values as function of the altitude, and compare the results with theory.

A) Altitude Region 85 to 155 km

1. Spectral Index (-4.5 ± 0.5). Irregularities with spectral indices in this range were observed in the height region 85 to 95 km in all three flights (see Figs. 1–3). The spectrum of these irregularities is steeper than those due to crossfield instabilities, these latter having a spectral index of about -3.0 (Sato, 1971; Prakash et al., 1971 b). We conclude from the greater absolute value of the spectral index that the observed irregularities are produced in a secondary process from crossfield generated irregularities. In the height region from 85 to 95 km the vertical Hall field is about 2 mV/m to 4 mV/m while at the 105 km region it is higher by a factor of about ten (Subbaraya et al., 1972). The scale size of irregularities generated by crossfield instability is given by $A/(EL)^{1/2}$ where A is a constant, E is the vertical Hall field and L is the logarithmic density gradient (Reid, 1968). The electric field is small at heights below 95 km. Therefore only larger scale size irregularities should primarily appear in this height range. The occurrence of meter scale size irregularities (1 to 15 m) is explained as being due to a decay into irregularities of smaller scale size. Because of this secondary process the spectrum of the 1 to 15 m scale irregularities in the 85 to 95 km range is steeper than found from theory.

2. Spectral Index (-3.0 ± 0.5). Values of the spectral index in this range were observed in the height region 95 to 120 km at night but from 95 to 105 km and from 145 to 155 km in the evening flight. At noon such values occured only from 95 to 98 km. These irregularities must be generated by cross field instabilities for which the spectral index is -3.0 (Sato, 1971; Prakash et al., 1971 b), in agreement with theory. We discussed this in detail in our earlier publications.

3. Spectral Index (-1.5 ± 0.5). Values in this range were observed only in our noon flight in the height range 98 to 100 km. Irregularities with this flatter spectrum would be generated by a combination of cross field and two stream instability. As will be discussed later, the two stream instability occurs only when the electron drift velocity is greater than 360 m/s. However Prakash et al. (1976), found around 99 km this value to be only 200 m/s, exceeding ion acoustic velocity only at 107 km height. Thus the two stream instability can produce irregularities only near 107 km. But since two stream instability generated irregularities are able to move vertically upward as well as downward (Balsley and Farley, 1971), the irregularities observed near 99 km may be a combination of locally generated cross field instabilities with those produced near the 107 km level by two stream instability. These latter irregularities have a flat spectrum such that the mixture must show a spectral index shifted towards the positive side, though less positive than pure two stream irregularities.

4. Spectral Index $(+0.5 \pm 0.5)$. Irregularities with such large positive spectral index were observed in the height range from 100 to 110 km. The amplitude of these irregularities is a maximum at 107 km where the electron drift velocity was also found to be a maximum. These irregularities are certainly generated by the two-stream instability mechanism, the electron drift velocity exceeding 360 m/s, i.e. the ion acoustic velocity in the medium (Farley, 1963; Prakash et al., 1971 b, 1976). The positive spectral index shows that the two-stream instability can generate scale sizes less than 1 meter.

B) Altitude Region 160 to 200 km

Rocket induced irregularities were observed during the noon, evening and night time flights in the 160 to 200 km altitude range. These irregularities are produced in the wake region of the rocket. They were only detected when the rocket was subsonic (Prakash et al., 1969, 1970; Gurvich et al., 1969). It was shown by Liu (1969) that in the vicinity of spacecraft a potential well exists. In the present case the rocket potential was found to be negative with respect to plasma i.e. about -1.0 Volt (Gupta, 1970). In this potential well ions will get trapped and will oscillate as suggested by Liu (1969). It is likely that we have observed this ionic mode of oscillations. The frequency range of these oscillations was about 1 KHz, which lies in the vicinity of the ambient ion plasma frequency of about 5 KHz at 180 km during night. The spectral index of these irregularities lies between zero and $+3.0$. There was however a difference between the evening flight with spectral index values varying from $+1.5$ to $+3.0$ and the night flight for which it varried from zero to $+1.5$. Since the frequency of rocket induced oscillations should be proportional to the ion plasma frequency which is greater during evening hours than during midnight. It is therefore in agreement with theory that more positive spectral indices occur during evening hours than at night.

Conclusion

We have found five classes of irregularities which were observed in the equatorial E region. The classification was made after the main mechanisms producing irregularities are either the crossfield instability or the two-stream instability. However, in certain height ranges irregularities generated due to crossfield and due to two-stream instability are present simultaneously. In the wake region of the rocket irregularities are also produced by some kind of plasma instability. More theoretical work is to be done to understand rocket induced irregularities.

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